

Table 1.—Summary of drillhole data in the Low Wassie quadrangle, Missouri

MISSOURI GEOLOGICAL SURVE

020426 Sec. 25, T. 27 N., R. 4 W. +1,028 +833 Or-Og +653

021640# Sec. 21, T. 27 N., R. 3 W. +891 ~+800 Or-Og +516

023809 Sec. 22, T. 27 N., R. 4 W. +1,105 +900 Or-Og +780

025311# Sec. 27, T. 27 N., R. 3 W. +881 +790 Or-Og +431

PK-9 Sec. 25, T. 27 N., R. 4 W. +1020 -693 €d-€b

PK–10 Sec. 12, T. 26 N., R. 4 W. +1,000 -378 €dd–€d

PK-13 Sec. 35, T. 27 N., R. 4 W. +1,025 -689 €d-€b

PK-14 Sec. 9, T. 26 N., R. 3 W. +1,005 -514? €dd-€d

PK-15 Sec. 12, T. 26 N., R. 4 W +950

PK-17 Sec. 12, T. 26 N., R. 4 W. +990

PK-18 Sec. 11, T. 26 N., R. 4 W. +960

PK-19 Sec. 28, T. 26 N., R. 3 W. +925

PK-20 Sec. 26, T. 26 N., R. 3 W. +760

PK-22 Sec. 11, T. 26 N., R. 4 W. +935

PK-23\* Sec. 11, T. 26 N., R. 4 W. +1,000

PK-27 Sec. 35, T. 27 N., R. 4 W. +1,000

PK-29 Sec. 28, T. 26 N., R. 3 W. +1,016

PK-30 Sec. 36, T. 27 N., R. 4 W. +1,065 -677 €d-€b

PK-31 Sec. 6, T. 26 N., R. 3 W. +990 -392 €p-€dd

ASARCO/AMSELCO

Collar Contact Bottom Hole

elevation elevation elevation

-581 €d-€b

-1,045 €b-€l

-1,154 €b-€l

-502 €dd-€d

-1,097 €b-€l

-920 €b-Yr

-327 €dd-€d

-525 €d–€b

-647 €b-Yr

-1,185 €b-€l -1,199

-560 €dd-€d

-553 €dd-€d

-1,195 €b-€l

-377 €p-€dd

-1,074 €b-€l

-347 €p-€dd

-1,112 €b-€l

-1,095 €b-€l

-396 €dd-€d

[Elevations in feet; datum is mean sea level. nd, no data available. Or, Roubidoux Formation; Og, Gasconade Dolomite; Ote, Eminence Dolomite; Cp, Potosi Dolomite; Edd, Derby-Doerun Formation (usage of Missouri Geological

Sec. 28, T. 26 N., R. 3 W. +950

Sec. 25, T. 27 N., R. 4 W. +1,025

PK-44 Sec. 25, T. 27 N., R. 4 W. +1,010 -540 €dd-€d

COMINCO

STIOF

S ec. 29, T. 26 N., R. 3 W. +890 -285? €p-€dd

S ec. 34, T. 27 N., R. 3 W. +985 -428 €p-€dd

Collar Contact Bottom Hole

-1,110 €b-€l -1,12

-398 €dd-€d

-590 €d–€b

-798 €b-Yr

-845 €d-€b

-1,259 €b-€l

-1,095 €b-€l

-497 €dd-€d

-573 €d-€b

-1,075 €b-€l

-517 €dd-€d

-1,033 €b-€l

-422 €dd-€d

-730 €d-€b

-304 €p-€dd

-956 €b-€l

-442 €p-€dd

-1,066 €b-€l

-494 €p-€dd

-859 €d-€b

-1,187 €b-€l

-566 €p-€dd

-1,324 €b-€l

-487 €d-€b

-575 €dd-€d

-558 €b-Yr

-778 €d-€b

-1,187 €b-€l -1,20

-1,145 €b-€l -1,176

-709 €d-€b

-1,051 €b-€l -1,108

-1.028 €b-Yr -1.045

-675 €d-€b

-629 €dd-€d

Collar Contact Bottom Hole

-563 €b-Yr -565

-1,161 €l-Yr -1,176

-1,090 €b-€l

-1,125 €b-€l

-398 €p-€dd

-1081 €b-€l

-1229 €b-€l

-487 €p-€dd

-1,114 €b-€l

-587 €d-€b

-1,113 €b-€l

-426 €p-€dd

-411 €p-€dd

-1,130 €l-Yr -1,136

-1,106 €b-€l -1,108

-335 €p-€dd

83W 15 Sec. 22, T. 26 N., R. 3 W. +785

766–002\* Sec. 6, T. 26 N., R. 3 W. +1022

801–002\* Sec. 33, T. 27 N., R. 3 W. +1006

801–003 Sec. 7, T. 26 N., R. 3 W. +886

801–011 Sec. 18, T. 26 N., R. 3 W. +895

801–20 Sec. 20, T. 26 N., R. 3 W. +920

801–25–O Sec. 17, T. 26 N., R. 3 W. +940

-805 €d-€b -1,233 €b-€l -1,265 801–27–E Sec. 14, T. 26 N., R. 4 W. +990 -406 €p-€dd

801–009 Sec. 3, T. 26 N., R. 4 W.

801–005 Sec. 26, T. 26 N., R. 4 W. +820 -525 €p–€dd

801–19–W Sec. 16, T. 26 N., R. 3 W. +950 -420 €p–€dd

801–21–AB Sec. 21, T. 26 N., R. 3 W. +975 -409 €p–€dd

elevation elevation Number

Collar Contact Bottom Hole

-728 €d-€b -1,116 €b-€l -1,146

-445 €p-€dd

-1,062 €b-€l

-507 €p-€dd

-486 €p-€dd

74 €dd–€d

-778 €d-€h

-782 €d-€h

-844 €d-€h

-1,260 €b-€l

-451 €p-€dd

-1,111 €b-€l

-407 €p-€dd

-443 €p-€dd

-456 €p-€dd

-1,129 €b-€l

-402 €p-€dd

-1,010 €b-Yr

-379 €p-€dd

-445 €dd-€d

-1050 €b–Yr

-1,137 €b-€l -1,157

-991 €b-€l -1,002

-409 €p-€dd

-362 €p-€dd

-327 €p-€dd

-641 €d-€h

-485 €dd-€d

-1.059 €b-€l -1.09

-1,182 €b-€l -1,186

-699 €d-€h

-1208 €b-€l

-622 €dd-€d

74 €dd–€d

-1,153 €b-€l -1,18

-714 €d-€k

801–28–H S ec. 13, T. 26 N., R. 4 W. +985

801–38 S ec. 17, T. 26 N., R. 3 W. +920

801–40–AA Sec. 21, T. 26 N., R. 3 W. +980

Collar Contact Bottom Hole

-1,138 €b–€l -1,160

-1,181 €b-€l

-768 €b-Yr

-418 €p-€dd

-1,059 €b–€l

-1,122 €b-€l

+335 Og–O€e

-425 €p-€dd

-480 €dd-€d

395 €p-€dd

-1,090 €b-€l

-568 €p-€dd

-332 €p-€dd

-405 €dd-€d

-972 €b-€l

-432 €p-€dd

-1,087 €b-€l

-429 €p-€dd

-1,116 €b-€l

-368 €p-€dd

-435 €dd–€d

-495 €dd–€d

-460 €dd-€d

-650 €dd-€d

-1,268 €b-€l -1,275

-1,069 €b-€l -1,10

-1,097 €b-€l -1,127

801–41–Y Sec. 16, T. 26 N., R. 3 W. +960

801–43–BA Sec. 20, T. 26 N., R. 3 W. +905

801–44–T Sec. 20, T. 26 N., R. 3 W. +970

801–45–G Sec. 13, T. 26 N., R. 4 W. +940

801–46–F Sec. 14, T. 26 N., R. 4 W. +840

801–48 Sec. 15, T. 26 N., R. 4 W. +890

801–49–J Sec. 32, T. 27 N., R. 3 W. +1,030

801–50–Z Sec. 21, T. 26 N., R. 3 W. +960

801–58 Sec. 35, T. 26 N., R. 4 W. +920

801–60 Sec. 7, T. 26 N., R. 3 W. +865

801–61 Sec. 7, T. 26 N., R. 3 W. +855

801–63 Sec. 13, T. 26 N., R. 4 W. +980

-934 €b-Yr -965 801-66 Sec. 13, T. 26 N., R. 4 W. +915 -515 €p-€dd

801–59 Sec. 2, T. 26 N., R. 4 W.

Survey, 1979): £d. Davis Formation: £b. Bonneterre Formation: £l. Lamotte Formation: Yr. Proterozoic basement, rhyolite and rhyolitic porphyry except for one locality (PK-46) reported as granite (possibly porphyritic rhyolite?).

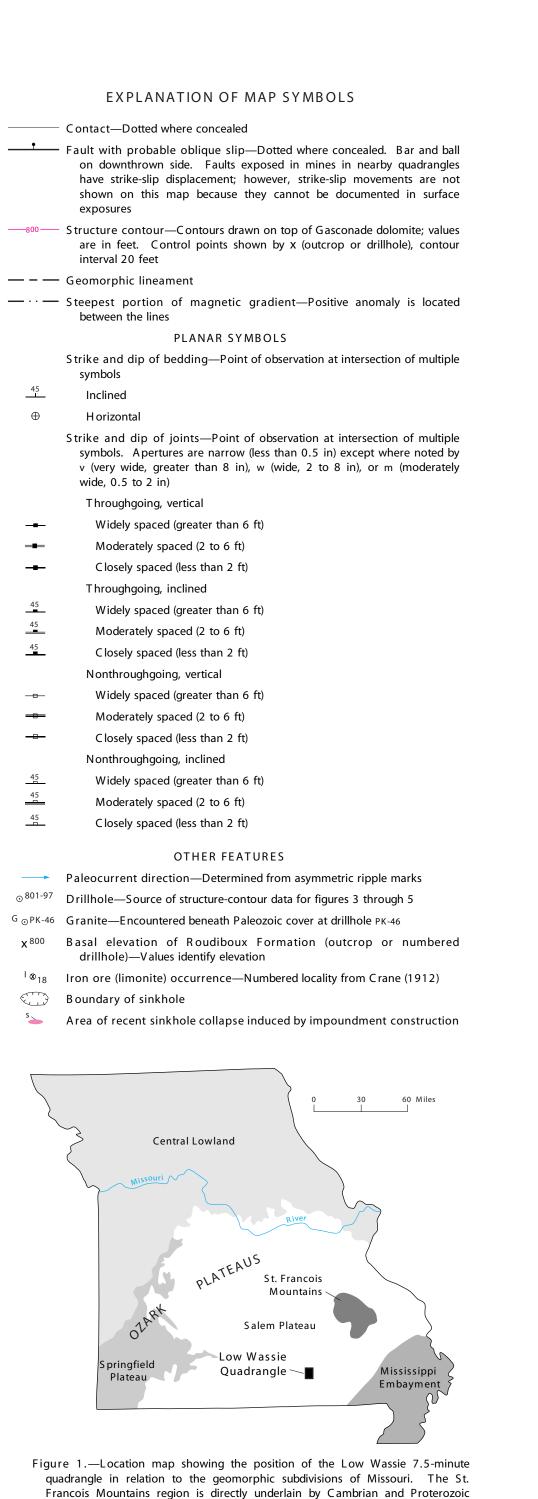
PK-42 Sec. 12, T. 26 N., R. 4 W. +915

76W 20 S ec. 22, T. 27 N., R. 3 W. +951

S ec. 35, T. 26 N., R. 3 W +706

Sec. 22, T. 26 N., R. 3 W.

79W 03 Sec. 34, T. 27 N., R. 3 W.



is the youngest deposit. Or, Roubidoux Formation; Og, Gasconade Dolomite; Qa,

INTRODUCTION

The Low Wassie 7.5-min quadrangle is located in south-central Missouri within the

Salem Plateau region of the Ozark Plateaus province (fig. 1) (Fenneman, 1938; Bretz,

1965; Imes and Emmett, 1994). The quadrangle is dominantly rural in character, the

land being mostly used for lumber growth and to a much lesser extent for farming.

Along U.S. Route 60, which runs along the northern border of the map, the southern

fringes of the town of Winona extend slightly into the quadrangle. The map area has

an average topographic relief of about 470 ft, with elevations ranging from slightly

less than 660 ft along the southeastern quadrangle margin to more than 1,120 ft in

the northwestern area. A broad, northwest-trending ridge, the crest of which is

followed by Old Tram Road, cuts across the central part of the quadrangle. This ridge

crest forms the surface watershed divide between the Current River (fed by Pike Creek

and its tributaries in the north and east) and the Eleven Point River (fed by Hurricane

Creek, Possum Trot Hollow, Dry Fork, and their tributaries in the south and west);

neither river occurs in this quadrangle. In very wet weather, streams flow along the

valley floors. In dry or even moderately dry weather, however, most surface water

drains into the ground and exits by way of a karstic network of underground cave and

fracture systems. This leaves the well-developed system of stream valleys underfed

with water during most of the year. Exceptionally persistent water flow and associated

hydrophytic vegetation only occur along Horse Trough Hollow and the unnamed

tributary of Pike Creek that lies northeast of and follows the same strike as Horse

The general geologic setting of the quadrangle is shown on the Geologic Map of

Missouri at a scale of 1:500,000 (Anderson, 1979), which was based on

Wassie area) at a scale of 1:62,500 by Hebrank (1977). Detailed mapping in the Low

Wassie quadrangle at a scale of 1:24,000 was done during the winter months of

1995 and 1996, when there was minimal vegetation to obscure outcrops. Bedding

attitude and joint attributes and orientations were recorded from bedrock exposures

wherever observed. Where exposed in outcrop, contact elevations were determined

The Low Wassie map area is underlain by 1,500 to 2,500 ft of lower Paleozoic

marine strata that consist mostly of dolomite, chert, sandstone, and orthoquartzite.

From oldest to youngest, these units are the Upper Cambrian Lamotte Sandstone, the

Bonneterre Formation, the Davis Formation, the Derby-Doerun Dolomite of Weller

and St. Claire (1928), the Potosi Dolomite, the Upper Cambrian to Lower Ordovician

Eminence Dolomite, and the Lower Ordovician Gasconade Dolomite, Roubidoux

Formation, and Jefferson City Dolomite. Only the last three units are exposed at the

surface in the quadrangle. The dolomites contain many caves, which have been

described by Bretz (1956), Eddleman (1977), and Weaver (1992). The largest in the

map area is New Liberty Cave, which is 3,630 ft long as mapped by the Cave

Research Foundation (Scott House and Jerry Wagner, 1992, unpub. data). The

nearly flat lying, dolomite-rich rocks unconformably overlie volcanic rocks and some

granite bodies of Middle Proterozoic age that make up the bulk of the 1,500 to 1,400

differentiation and mapping of these terraces across the map area was beyond the

scope of the present project. In several upland areas of the map, thin patchy deposits

of subrounded to rounded cobbles and pebbles of chert, sandstone, and quartzite were

801–108 Sec. 17, T. 26 N., R. 3 W. +840

801–109 S ec. 18, T. 26 N., R. 3 W. +910

801–110 Sec. 18, T. 26 N., R. 3 W. +900

801–124 Sec. 31, T. 26 N., R. 3 W. +900

801–125 S ec. 34, T. 27 N., R. 4 W. +1,020

801–126\* Sec. 14, T. 26 N., R. 4 W. +945

801–127 S ec. 14, T. 26 N., R. 4 W. +990

801–132 Sec. 7, T. 26 N., R. 3 W.

Along Hurricane Creek, several levels of surficial terrace deposits occur. Detailed

by hand-leveling from a point of known elevation.

Ma St. Francois terrane (Kisvarsanyi, 1979, 1981).

Collar Contact Bottom Hole

-1,087 €b-€l -1,103

-497 €dd-€d

-425 €p-€dd

-489 €dd-€d

-1,048 €b-€l -

-43 €p-€dd

-1,115 €b-€l

-418 €p-€dd

-519 €p-€dd

-582 €dd-€d

-1,209 €b-€l

-509 €p-€dd

-1,243 €b–€l

-487 €p-€dd

-1,152 €b-€l

-740 €d-€b

-1,145 €b-€l -1,164

-1,156 €b-€l -1,178

-1,121 €b-€l -1,158

-43 €p-€dd

-681 €d-€b

-985 €b-Yr

-1,170 €b-€l -1,185

-505 €dd-€d

econnaissance mapping of the Birch Tree 15-min quadrangle (including the Low

alluvium. Vertical exaggeration is x10.

Figure 4.—Structure-contour map of the Low Wassie quadrangle showing the basal surface of the Davis Formation. Steepest portions of the gradient marking the sides of the positive magnetic anomaly crossing this area also are shown. rocks, the Salem Plateau by Cambrian and Ordovician rocks, the Springfield Plateau by Mississippian rocks, the Central Lowland Province by Ordovician to Pennsylvanian rocks and Quaternary periglacial sediments, and the Mississippi Embayment by Cretaceous to Quaternary sediments (adapted from Imes and Figure 5.—Structure-contour map of the Low Wassie quadrangle showing the basal surface of the Bonneterre Formation and underlying lithologies. Steepest portions of the gradient marking the sides of the positive magnetic anomaly crossing this area also are shown. [Use with figures 3, 4 and 5] - Structure contour—Measurements in feet. Queried where uncertain; dashed where inferred. Contour interval 100 feet. Fault—Showing relative movement. U, up; D, down Figure 2.—Schematic cross section showing the three levels of terraces along Approximate updip limit of Lamotte Sandstone—tick marks point downdip Hurricane Creek. QTg<sub>1</sub> is the oldest deposit, QTg<sub>2</sub> is the middle deposit, and Qt<sub>3</sub> ----- Boundary of positive magnetic anomaly

> observed (QTg). These deposits may be as high as 300 ft above the present river level and possibly represent fluvial sediments from the major streams that were deposited prior to the downcutting of the present steep valleys. It is also possible that some especially isolated cases on high conical knobs may be sinkhole fills that have weathered out into inverted topography. At lower levels near the present valley floors, younger and more extensive terrace deposits (Qt) occur, which are probably of late Pleistocene age (Hayes, 1985; Albertson and others, 1995). Glacial-age loess is thin or absent over most of the Salem Plateau (Ebens and Connor, 1980). Even so, the Low Wassie region includes extensive areas of soils with a loess component (Gott, 1975). In most areas, these soils do not constitute a mappable geologic unit because they are thin and intimately intermingled with underlying clayey residuum due to bioturbation. In many of the larger sinkholes, however, loess deposits capped by Holocene mucks (Qm) are thick enough to be mapped as a separate unit. Only gray silts, probably Wisconsinan loess, were observed, but older loess deposits may be present locally at depth beneath them Along deeper and steeper valley walls, especially along Hurricane Creek, there are

•-561 Data point from well log—Measurements in feet. nd, no data; G, granite

Figure 3.—Structure-contour map of the Low Wassie quadrangle showing the basal

of the positive magnetic anomaly crossing this area also are shown.

surface of the Potosi Dolomite. Steepest portions of the gradient marking the sides

however, there is a pervasive mantle of residuum that represents the in-place weathering of fresh bedrock into soil. Generally, carbonate material has been leached away, leaving behind a residue of pebbles, cobbles, and boulders of angular chert, quartzite, and sandstone floating in a matrix of clayey silt to silty clay. Because this material is nearly ubiquitous at the land surface, it has not been separately mapped from its parent bedrock, except for residuum of the Jefferson City Dolomite. This is because all observed material derived from the Jefferson City has been reduced to residuum, and no fresh bedrock exposures are known or even inferred within the map On most slopes, downhill creep of residual soils produced a thin mantle of colluvium along most valley walls. This material is exceptionally thick in the upper

prominent intermittent exposures of cherty Gasconade Dolomite. In upland areas,

axes of the first-order drainages ("hillslope hollows" of Reneau and others, 1990), where its convergence with shallow ground water contributes to special ecological and geotechnical conditions (Robert B. Jacobson, U.S. Geological Survey, written commun., 1997). Because this veneer is nearly ubiquitous but thin, in most areas it is not mapped as a separate unit. In a few areas, however, there has been large-scale slumping or landsliding of rock or soil. Where observed, these colluvial materials are

## STRUCTURAL GEOLOGY

ft/mi. Only one fault and associated splay, here named the Low Wassie fault, in the northeastern corner of the map area, has been positively identified. The trace of the fault is hidden beneath alluvium and colluvium, but its presence can be inferred because at least 70 ft of downward displacement has occurred on the southwestern side of the fault. From this limited information, it is impossible to determine if the fault is normal, reversed, strike slip, or oblique slip. Another possible structural feature observed in surface mapping is a lineament located along the axis of Horse Trough Hollow in the northwestern part of the quadrangle. Beyond Horse Trough Hollow to the northeast, this feature continues

across the watershed divide between the Current and Eleven Point Rivers through

801–136 Sec. 31, T. 26 N., R. 3 W. +920

801–138 Sec. 2, T. 26 N., R. 4 W. +925

801–143 Sec. 7, T. 26 N., R. 3 W. +980

801–144 Sec. 18, T. 26 N., R. 3 W. +853

801–146 Sec. 14, T. 26 N., R. 4 W. +800

801–147 S ec. 26, T. 26 N., R. 4 W. +955

801–155 S ec. 23, T. 26 N., R. 4 W. +910

801–157 Sec. 15, T. 26 N., R. 4 W. +1,035

801–166 S ec. 34, T. 27 N., R. 4 W. +953

at hole location indicate. Source of discrepancy uncertainty

Reported collar elevation about ten feet higher than map topographic contours

801–145 Sec. 18, T. 26 N., R. 3 W.

801–137 Sec. 36, T. 26 N., R. 4 W.

Collar Contact Bottom Hole

-1,156 €b-€l -1,188

-1,039 €b-Yr -1,042

-381 €p-€dd

-441 €dd-€d

-402 €dd-€d

-834 €I–Yr

-1,042 €I–Yr

-1,060 €b-€l

-378 €p-€dd

-629 €d-€b

-948 €b-Yr

-452 €p-€dd

-448 €p-€dd

-1,127 €b-€l

-1,299 €b-€l

-585 €p-€dd

-871 €d-€b

-461 €p-€dd

-1,120 €b-€l

801–135 Sec. 14, T. 26 N., R. 4 W. +960 -496 €p–€dd # Elevation of contact from Hebrank (1977).

-1129 €b-€l -1,

-1,116 €b-€l -1,15

-1,132 €b-€l -1,13

Strata in the quadrangle generally dip gently toward the southeast at about 20

another unnamed linear valley. These two stream systems maintain the most persistent surface-water flow to be found within the map area, as indicated by the hydrophytic vegetation along their valley floors. Additionally, large sinkholes are developed along this trend that are prominently elongated along the axis of the lineament, and cataclastic shears occur in sandstone float along the valley. The similar elevation of the base of the sandstone-to-quartzite interval in the upper part of the Roubidoux Formation (indicated by dashed line), exposed both northwest and southeast of this lineament, suggests a lack of any significant vertical movement along

Figure 7.—Rose diagrams showing the dominant joint trends

developed above the positive magnetic anomaly (A) and to either

side of it (B). Note that the pattern in A is more diffuse than the

pattern in B and that there is a weakly developed north-northwest

joint trend in A that is not present in B. Joint sets in the Gasconade

Dolomite and Roubidoux Formation were weighted by counting

closely spaced joint sets three times, medium-spaced sets two times,

and widely spaced sets once. This system approximates the relative

passageway trends (C) present in the New Liberty Cave were

weighted according to the length of each trend segment (in meters).

There is a weak correlation between the trends of the cave

passageways and the northeast-trending joint set, and no correlation

with the northwest trending joint set.

importance of each set relative to the volume of the rocks. Cave

In the subsurface, beneath the Roubidoux Formation and Gasconade Dolomite, successively older lower Paleozoic stratigraphic horizons show increasing structural relief as they approach the Proterozoic floor beneath them (figs. 3–5). This relief appears to be directly related to differential compaction of strata above an irregular topographic surface that was buried by sediments from early Paleozoic transgressions across the region. Among these subsurface features is a prominent series of large northwest-trending ridges that cross the map area. These ridges occur within a positive magnetic anomaly along the same trend (map, figs. 5-6). Nothing was observed in the field to suggest that the magnetic gradients on either side of these ridges correspond to faults, but due to poor exposure this remains a possibility. Joints developed directly above the positive magnetic anomaly show a more diffuse pattern than the joints to either side of it (fig. 7). Additionally, there is a weakly developed joint trend above the positive magnetic anomaly that parallels the trend of the ineament but is absent from the rocks to either side of it. Whether this fracturing is due to sediment drape associated with compaction, or whether tectonism has affected the development of joints above this area cannot be determined. The rocks of this quadrangle are pervasively and complexly jointed. Joints confined pedding planes into surrounding beds are classified as throughgoing. Measurement of joint aperture includes all effects of dissolution along the joint planes (Harrison and others, 1996). Cumulative orientations of all joint measurements observed in outcrop

the overlying Roubidoux Formation. Joints in the Gasconade are similar in orientation to those of the lower Roubidoux, and both types are dominantly vertical. At higher elevations within the quadrangle, sandstone and quartzite strata in the upper part of the Roubidoux commonly are broken and tilted in a chaotic pattern patterned area of Roubidoux outcrop). This appears to be the result of extensive dissolution of interbedded and underlying dolomites, which has created subsurface voids into which the solution-resistant overlying sandstones and quartzites have collapsed. Joint trends of these sandstones and quartzites of the upper Roubidoux have a greater scatter than the joint trends in strata of the Gasconade and lower part of the Roubidoux, due to rotation during collapse (figure 8C). Recent examples of such collapse occur in T. 27 N., R. 3 W., sec. 30 where small sinkholes have formed as a result of ground collapse induced by the construction of a stream impoundment

are shown in fig. 8 for the Gasconade Dolomite and the upper and lower portions of

## ECONOMIC GEOLOGY

dam (Aley and others, 1972).

-768 €d-€b -1,180 €b-€l -1,200

-604 €p-€dd

-1,308 €b-€l

-1.281 €b-€l

-415 €p-€dd

-708 €d-€b -1,096 €b-€l

-1,097 €b-€l

-408 €p-€dd

-1,095 €b-€l

-438 €p-€dd

-1,120 €b-€l

-1,150 €b-€l -1,20

-472 €p-€dd

-1,161 €b-€l

-1,098 €b-€l

-1,089 €b-€l -1,10

Copper, iron, manganese, and lead have been mined in Shannon County, and copper and iron have been mined in adjacent areas north and east of the Low Wassie quadrangle (Bridge, 1930). Commercial quantities of iron ore have not been found in this quadrangle (Crane, 1912; Wharton and others, 1969). The quadrangle lies about 25 mi southwest of a mining district known as the Viburnum trend, which has produced large quantities of lead and zinc, mostly from the Cambrian Bonneterre Dolomite (Wharton and others, 1969; Thacker and Anderson, 1977; Goldhaber and others, 1995). The Bonneterre Formation has been explored for lead content by deep drilling within the Low Wassie quadrangle, but no mining has been attempted as yet. Gravel, derived from alluvial stream bottoms, and fill earth, derived from residuum, are widely available and are used locally for dam and road-base construction (Wharton and others, 1969).

## GROUND WATER

Water flow in the map region is largely subterranean, with surface flow only

occurring at times of abundant rainfall. Under flood conditions, local residents report that water pressure can build up in the cave systems and actually produce fountains that erupt from sinkholes in relatively low lying areas. During normal flow conditions, many streams to the west and south of the map area sink into the ground and later emerge at Big Spring to the east (Dreiss, 1983; Imes and Kleeschulte, 1995), which suggests that most of the ground water beneath the quadrangle flows east-northeast toward Big Spring across the grain of the surface drainage pattern. However, groundwater flow in the south-central part of the map area also has been documented southward to Huff Spring along the Eleven Point River in the Greer quadrangle (Imes and Kleeschulte, 1995). A recent dye study in the southwestern part of the Low Wassie quadrangle (T. 26 N., R. 4 W., sec. 36) demonstrated subsurface flow from Ballard Hollow southwestward to Wolfpen Spring in the Piedmont Hollow quadrangle (T. 25 N., R. 4 W., sec. 16) (J.L. Imes, oral commun., 1996). These variable flow directions indicate that the detailed ground-water flow pattern is complex. Within the map area, the Gasconade, Eminence, and Potosi Dolomites are the major stratigraphic units that produce ground water (Dreiss, 1983; Imes and Emmett, 1994). Collectively, these units are part of the regional Ozark aquifer that underlies the Salem Plateau (for example, Imes and Emmett, 1994). Water generally is abundant and readily available either from springs or drilled wells, although successful recovery of well water can be erratic depending on local variations in subsurface

## GEOLOGIC HISTORY

The oldest rocks known to underlie the quadrangle are thick accumulations o Middle Proterozoic felsite flows and tuffs (Yr) that were erupted and intruded by granite around 1,500 to 1,400 Ma (Van Schmus and Bickford, 1981) (fig. 9). North of the quadrangle, these rocks are exposed at the surface in the Winona, Stegall Mountain, Eminence, and Powder Mill Ferry 7.5-min quadrangles. In the map area, however, these rocks have been encountered only at depths of 1,500-2,500 ft in exploration drillholes drilled where the Lamotte Formation is thin or absent (fig. 5 and table 1). One drillhole in this area (table 1, PK-46) encountered rocks that were described tentatively as granite, but all others penetrated the rhyolitic volcanic rocks. These volcanic deposits were deformed, tilted, and subjected to uplift and erosion subsequent to their accumulation and prior to the Paleozoic Era. The regional relief on this buried erosional surface has been reported to be as much as 2,000 ft (Houseknecht and Ethridge, 1978; Kisvarsanyi, 1981; Orndorff and others, 1999).

jointing patterns and the presence or absence of caves. Water from caves can be

contaminated with red clay during periods of high water, rendering it undesirable for

In the early Paleozoic, the Ozark region was flooded by an extensive epicontinental sea that covered most of the midwestern part of the United States. In the map area, a southeast-trending string of felsite hills, with more than 800 ft of relief (fig. 5),

region probably was emergent and undergoing erosion in Triassic, Jurassic, and Early

Geologists, v. 76, no. 7, p. 1879–1894.

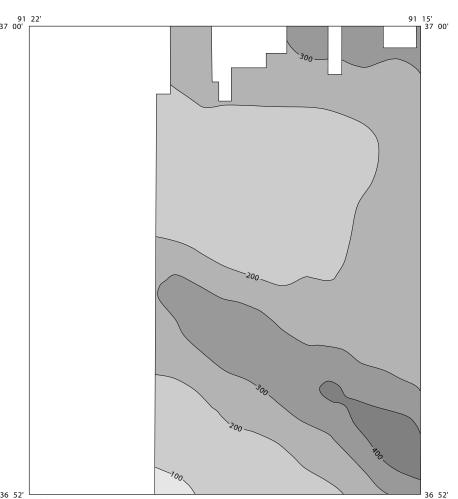
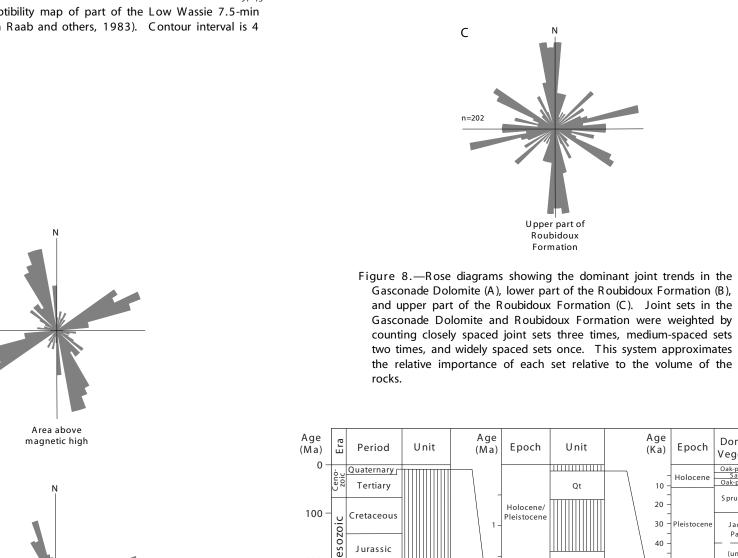


Figure 6.—Magnetic-susceptibility map of part of the Low Wassie 7.5-min quadrangle (adapted from Raab and others, 1983). Contour interval is 4



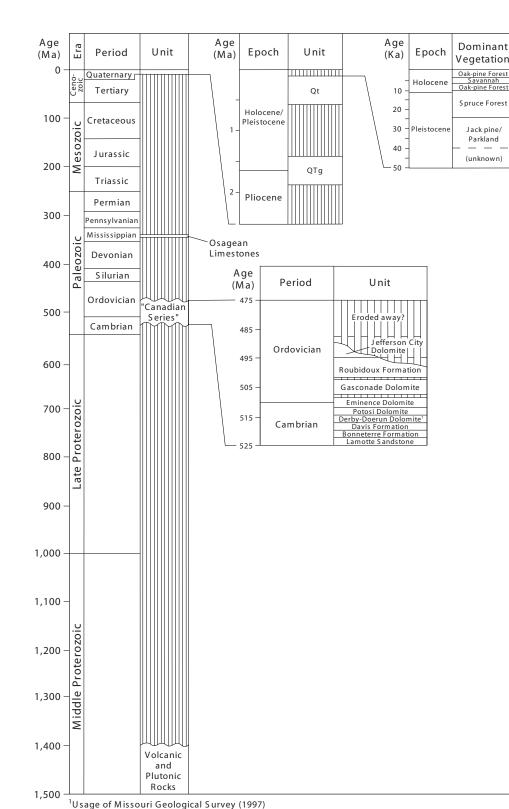


Figure 9.—Chart summarizing the age distribution of geologic units represented in the Low Wassie and adjacent quadrangles, as well as the late Pleistocene and Holocene vegetational record of the Ozark region in Missouri. Mississippian units are not present today in the Low Wassie area, but float from these units in the adjacent Birch Tree, Bartlett, and Winona quadrangles indicates that they probably were present in the past and have been removed by erosion. Vertical bars indicate time intervals for which there are no known deposits in this region. The far right column summarizes what is known of the vegetational history of the Salem Plateau (data from Mehringer and others, 1968, 1970; King, 1973; King and Allen, 1977; Smith, 1984). Time scale from Cowie and

eventually were covered by this sea and buried beneath its sedimentary deposits. The basal Paleozoic unit in the area, the sandstone-rich Upper Cambrian Lamotte Formation (£I), onlaps the flanks of these hills but does not extend across the top of them (cross section A-A'). Regionally, the Lamotte may be as much as 500 ft thick (Houseknecht and Ethridge, 1978), so local relief on the top of the Middle Proterozoic could be as much as 200 ft greater than has been shown on fig. 5.

During deposition of the overlying Bonneterre Dolomite (€b), algal reefs developed along the flanks of the remnant islands of Middle Proterozoic rocks that remained above the Late Cambrian sea (Lyle, 1977). These reefs, especially to the north along the Viburnum trend, later became the focus of precipitation of important lead deposits (Thacker and Anderson, 1977). The island hills were not entirely buried in the map area until near the end of deposition of the Bonneterre (see cross section A-A'), and they seem to have affected depositional patterns even after they were completely buried (figs. 3 and 4) through differential compaction of sediments deposited on and around their flanks. Deposition, mostly of carbonate sediments, continued through the rest of Cambrian time and into the beginning of the Ordovician, sequentially accumulating the Davis Formation (£d), Derby-Doe Run Dolomite (usage of Missouri Geological Survey, 1979) (€dd), Potosi Dolomite (€p), and Eminence Dolomite (0€e).

There was a regression of the sea in earliest Ordovician time, and an unconformity developed on top of the previously deposited dolomites and sandstones. A subsequent transgression of the sea in the Early Ordovician resulted in deposition of the Gasconade Dolomite (Og), which includes at its base the Gunter Sandstone Member. The abundance of carbonate stromatolites throughout the Gasconade indicates that it primarily was deposited in shallow marine waters. Fossils are rare in the upper part of the Gasconade within the map area, although Harrison and others (1996) reported the presence of planispiral gastropods and cephalopods from cherts within this unit to the northwest at Fort Leonard Wood. Conodonts collected from two localities (T. 26 N., R. 4 W., sec. 3, locality with 880-ft spot elevation for top of Gasconade Dolomite; T. 26 N., R. 3 W., sec. 29, bluff on west bank of Hurricane Creek) are indicative of an early Early Ordovician (early Ibexian) age (J.E. Repetski, U.S. Geological Survey, written commun., 1997).

Deposition across the contact between the Gasconade Dolomite and the Roubidoux Formation (Or) generally has been described as continuous (Heller, 1954; Carver, 1961). Even so, local channeling along the contact can be seen along the bluff north of Dry Fork, (T. 26 N., R. 3 W., sec. 27), which demonstrates local relief of 35 ft on the basal contact of the Roubidoux. The absence of conglomerate at the base of this trough suggests that it was a tidal channel rather than a channel within a fluvial During deposition of the Roubidoux Formation, quartz sand spread across the sea

floor and accumulated in large but discontinuous sheets that were separated by areas of continuing carbonate deposition. These sand sheets and intervening volumes of carbonate rock later became the sandstones, orthoquartzites, and dolomites that compose the lower part of the Roubidoux Formation. The influx of quartz sand later waned and a thick sequence composed almost entirely of carbonate rocks then accumulated to form the middle part of the Roubidoux. Subsequently, a second major pulse of quartz sand was deposited throughout the Salem Plateau area in large discontinuous sheets, which became the sandstones and orthoquartzites that characterize the upper part of the Roubidoux.

Both major pulses of quartz sand were transported by currents to the southern Missouri region from northern Michigan and the Canadian Shield (Carver, 1961). Local sedimentary structures indicate that the dominant transport direction was from the east-northeast toward the west-southwest and southwest (Carver, 1961). As with the Gasconade, all of the Roubidoux appears to have accumulated in shallow water because dolomite-rich intervals contain common algal stromatolites and oolites, while sandstone-rich intervals contain abundant desiccation cracks and both symmetric and asymmetric ripple marks suggestive of widely variable current directions. Fossils generally are rare, although impressions of snails (mostly Lecanospira) locally are ommon in cherts and sandstones. Heller (1954) reported the occurrence of brachiopods, cephalopods, and trilobites from this formation elsewhere within the Salem Plateau, and Harrison and others (1996) reported the occurrence of conodonts indicative of an early Early Ordovician (early to middle Ibexian) age. Carver (1961), on the basis of petrographic studies, concluded that most of the fossil remains of gastropods and brachiopods in this unit were obscured by the process of

After deposition of the Roubidoux, a number of other Lower Ordovician units accumulated which are preserved elsewhere in and around the Ozark Plateaus. These may have been present at one time across the map area, but only the immediately overlying Jefferson City Dolomite is still partially preserved as residuum (QTjcr) in the northwestern corner of the map area. Other units, if once present, were eroded away as a result of a major uplift of the entire Ozark dome region in middle Paleozoic time. This is indicated by the complete absence of Upper Ordovician through Devonian rocks across this region, and by the local persistence of Mississippian rocks lying directly on Ordovician rocks.

Local residual concentrations of fossiliferous Mississippian (Osagean) chert, probably material that accumulated in paleo-sinkholes, are found to the west (Birch Tree 7.5-min quadrangle), northwest (Bartlett 7.5-min quadrangle), and north (Winona 7.5-min quadrangle) of the Low Wassie quadrangle (Bridge, 1930). The parent units of these residual rocks assuredly extended across the Low Wassie quadrangle, but they have been stripped away by erosion. Pennsylvanian deposits, although unknown from the Low Wassie area, are known from the northern Ozark region (Unklesbay and Vineyard, 1992). This suggests that a regional transgression may have occurred across the Ozark region in Pennsylvanian time, though this possibility remains unproven. No evidence has been found to suggest any Permian deposition in the Ozark region.

The early Paleozoic carbonate rocks in the Low Wassie quadrangle have been strongly affected by late Paleozoic warm sodium-calcium-chloride brines that migrated northward from the Arkoma basin. As these brines moved through the Lamotte Sandstone, they transported lead in solution toward the St. Francois Mountain area. In areas where the Lamotte pinches out against Precambrian basement knobs, the solutions probably were forced upward into the Bonneterre Dolomite (Goldhaber and others, 1995), where they interacted with dolomitic strata and mixed with other waters, locally precipitating large quantities of galena, sphalerite, chalcopyrite, and pyrite (Leach and Rowan, 1986; Panno and Moore, 1994). The resultant deposits have been mined regionally on an extensive scale. Samples of the mineralized naterial retain paleomagnetic pole positions that were imprinted in latest Pennsylvanian to earliest Permian time (Wu and Beales, 1981; Wisniowiecki and others, 1983), suggesting that the mineralization of these samples occurred at about 290 Ma (fig. 9). Secondary dolomitization of the Cambrian and Ordovician carbonate units in the Salem Plateau probably occurred concurrently with the emplacement of the galena and pyrite (Gregg, 1985), and is locally imprinted upon pervasive lolomitization that occurred before lithification of the ancestral carbonate muds from

which these units were formed (Carver, 1961). The Mesozoic history of the Ozark region is virtually unknown. Deposits of this age, if they once were present, subsequently have been eroded from the area. On the basis of depositional patterns in Mesozoic rocks throughout North America. the Ozark

was covered by an inland seaway that covered most of the United States west of the present Mississippi River (Smith and others, 1994). Glauconitic Cretaceous sediments, now stripped away, may have been the source of the iron contained in the "primary limonites" that occur locally in the southeastern Ozark region (Potter, 1955, p. 125). Although missing today from the Ozark Plateaus, Upper Cretaceous deposits are preserved to the southeast in the Mississippi Embayment. The Ozark region may have been covered by the sea in early Paleocene time (Smith and others, 1994), but throughout the remainder of the Tertiary, the Ozark dome seems to have been above sea level and undergoing weathering and erosion. This implies that the existing stream patterns were established no earlier than the Tertiary Period. The widespread occurrence of thick residual soils (for example, QTrjc in the map area) indicates that the Ozark region has undergone prolonged weathering at least since mid-Tertiary time (McKeown and others, 1988). The existing, rolling upland topography, with its deeply incised stream valleys, probably resulted from regional Quaternary uplift, accompanied by the capture of much of the ancestral Gasconade River drainage basin by tributaries of the White River (Elfrink and Siemens, 1997, 1998). The development of three Pleistocene to Pliocene(?) terrace deposits at successively lower elevations, as seen along Hurricane Creek (fig. 2), indicates that uplift and downcutting were episodic and not continuous (Flint, 1941). Whether these episodic intervals of uplift, and concomitant cave development, resulted in the formation of regional flat erosional surfaces called peneplains (Bretz, 1956, 1962, 1965), or whether the existing landforms represent a dynamic equilibrium between bedrock hardness and erosion (Hack, 1960; Reams, 1968) remains controversial. Unpublished work has been done on the Pleistocene and Holocene history of the map region (Smith, 1984; Huber, 1985); these reports focus mainly on the loess and organic-rich silts and clavs in sinkholes and the finer sediments along the alluvial plains of larger streams. Northwest of the map region, in Benton and Hickory Counties, a detailed stratigraphic, climatic, and vegetative record has been established (Mehringer and others, 1968, 1970; King, 1973; Havnes, 1985). In mid-Wisconsinan time, from more than 40 ka to about 25 ka, the western Ozark region had an open jack pine to parkland vegetative cover (fig. 9). This cover was replaced in late Wisconsinan time (about 25 to 13.5 ka) by spruce forests. In the latest Wisconsinan and early Holocene (about 13.5 to 9 ka), the warming postglacial climate caused the spruce forests to be replaced gradually by oak, pine, and hickory forests. During this period of transition around 10.5 ka, the earliest known paleo-Indians arrived in the Ozark region (Haynes, 1985). From about 8.7 ka until about 5 ka, the climate apparently became somewhat drier than at present, for the pollen record indicates that during

Cretaceous time. During the Late Cretaceous, however, the Ozark region probably

(King and Allen, 1977; Smith 1984). Since then, the climate has become wetter, and oak, pine, and hickory forests have reclaimed the prairie inliers. In Shannon and Oregon Counties, late Pleistocene cave deposits yielded the remains of a few kinds of extinct animals, such as the stilt-legged deer (?Sangamona sp.), short-faced bear (Arctodus simus), jaguar (Panthera cf. onca), and dire wolf (Canis dirus). Most fossils, however, are from animals still living in the area today, such as the porcupine (Erithizon dorsatum), beaver (Castor canadensis), deer (Odocoileus sp.), cougar (Felis concolor), black bear (Ursus americanus), and gray wolf (Canis lupus) (Hawksley, 1986). No Pleistocene vertebrate fossils older than

Wisconsinan have been found in any of the caves of Missouri (Reams, 1968).

that time the Ozark uplands locally were invaded and replaced by prairie and parkland

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GEOLOGIC MAP OF THE LOW WASSIE QUADRANGLE, OREGON AND SHANNON COUNTIES, MISSOURI

Collar Contact Bottom Hole

-806 €d-€b

-783 €d-€b

-475 €p-€dd

-1,133 €b-€l

-497 €p-€dd

-790 €d-€b

-703 €d-€b

-1168 €b-€l

-428 €p-€dd

-698 €d-€b

-493 €p-€dd

-464 €p-€dd

-757 €d-€b

-1,052 €b–€l

-468 €p-€dd

-738 €d-€b

-502 €p-€dd

-390 €p-€dd

-655 €d-€b

-475 €p-€dd

-1,092 €b-€l

-1,080 €b-€l -1,103

-1,185 €b-€l -1,195

-1,051 €b-€l -1,086

-1,107 €b-€l -1,124

-1,123 €b-€l -1,138

-1,198 €b-€l -1,208

-1,171 €b–€l -1,184

-1,210 €b-€l -1,23

801–69–CP Sec. 19, T. 26 N., R. 3 W.

801–74 Sec. 19, T. 26 N., R. 3 W.

801–75 Sec. 19, T. 26 N., R. 3 W. +830

801–76 Sec. 27, T. 27 N., R. 4 W. +1,090

801–80 Sec. 13, T. 26 N., R. 4 W. +975

801–81 Sec. 13, T. 26 N., R. 4 W. +960 -433 €p–€dd

801–77 Sec. 13, T. 26 N., R. 4 W.

-1,191 €b-€l -1,103

-1,205 €b-€l

801–82 Sec. 13, T. 26 N., R. 4 W. +955

801–83 Sec. 13, T. 26 N., R. 4 W. +920

801–84 Sec. 13, T. 26 N., R. 4 W. +920

801–96 S ec. 24, T. 26 N., R. 4 W. +910

801–97 Sec. 24, T. 26 N., R. 4 W. +890

801–99 Sec. 13, T. 26 N., R. 4 W. +900

801–103 Sec. 17, T. 26 N., R. 3 W. +860

801–104 S ec. 13, T. 26 N., R. 4 W. +900

801–101 Sec. 13, T. 26 N., R. 4 W. +960 -453 €p-€dd

801–102 Sec. 19, T. 26 N., R. 3 W. +910 -480 €p-€dd

801–107 Sec. 14, T. 26 N., R. 4 W +950 -462 €p-€dd

801–100 Sec. 13, T. 26 N., R. 4 W.

801–98 Sec. 25, T. 26 N., R. 4 W.

801–88 Sec. 8, T. 26 N., R. 3 W.